

GREAT LAKES NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE GREAT LAKES NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to -4.0 , a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

Literature Cited

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. *Environmental Management*. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. *Atmospheric Environment* 31(11):1695-1708.

U.S. National Park Service. 2003. Ozone Sensitive Plant Species on National Park Service and US Fish and Wildlife Service Lands. NPS D1522. Natural Resource Report NPS/NRARD/NRR-2003/01. Air Resources Division. Denver, CO. 21 pp. (Available at www2.nature.nps.gov/ard/pubs/index.htm)

SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE GREAT LAKES NETWORK

Park	Code	State	Risk	O3 Data
Apostle Islands NL	APIS	WI	low	kriged
Grand Portage NM	GRPO	MN	low	kriged
Indiana Dunes NL	INDU	IN	high	monitored
Isle Royale NP	ISRO	MI	low	kriged
Mississippi NRR	MISS	MN	low	kriged
Missouri NRA	MNRR	NB/SD	low	kriged
Pictured Rocks NL	PIRO	MI	moderate	kriged
Saint Croix/Lower St. Croix NSR	SACN	WI	low	kriged
Sleeping Bear Dunes NL	SLBE	MI	high	kriged
Voyageurs NP	VOYA	MN	low	monitored

APOSTLE ISLANDS NATIONAL LAKESHORE (APIS)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Aster macrophyllus</i>	Big-leaf aster	Asteraceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus banksiana</i>	Jack pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours

above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for APIS					
	1995	1996	1997	1998	1999
Sum06	7	3	5	7	9
W126	12.1	10.0	10.0	15.2	17.8
N60	168	106	122	217	268
N80	11	5	4	12	36
N100	1	0	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at APIS					
	1995	1996	1997	1998	1999
Month 1	0.50	1.01	0.90	2.33	-0.94
Month 2	-3.55	1.47	-2.25	-2.44	3.50
Month 3	-0.08	-2.02	0.55	-1.69	-1.23

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at APIS					
	1995	1996	1997	1998	1999
April	0.74	1.47	-2.25	-2.44	-0.94
May	0.50	-2.02	0.55	-1.69	3.50
June	-3.55	1.06	-0.86	1.38	-1.23
July	-0.08	3.36	1.41	-3.24	5.56
August	3.63	-1.04	0.69	-2.72	-0.70
September	-0.61	-0.85	-0.41	-3.22	-1.70
October	5.08	2.86	1.14	-1.74	-0.90

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than one hour in which the concentration exceeded 100 ppb and in most years ambient ozone did not reach this concentration. These levels of exposure are not likely to injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. Soil moisture levels show that each year generally had one month of mild or moderate drought, and there does not appear to be any association between the levels of ozone and drought over the five-year period. The relatively uniform levels of ozone exposure also make it difficult to assess

relationships between the W126 ozone exposure index and soil moisture. Levels of drought varied widely among years and ranged from five months of mild to severe stress in 1998, the year with the second highest level of ozone, to single months of severe and moderate moisture stress in 1995 and 1997, years of moderate and low ozone respectively. Two months of drought stress occurred in 1996, a low ozone year, and 1999, the highest ozone year. No associations between the W126 levels of ozone and soil moisture are apparent in these observations.

The low level of ozone exposure at Apostle Islands National Lakeshore makes the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 indices of exposure are satisfied, and exposure to levels greater than 100 ppb are rare. Months of drought stress are distributed over the five-year period, and are at times severe or numerous. These levels of drought limit the uptake of ozone and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, big-leaf aster, quaking aspen, Allegheny blackberry, and cut-leaf coneflower.

GRAND PORTAGE NATIONAL MONUMENT (GRPO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GRPO					
	1995	1996	1997	1998	1999
Sum06	5	3	5	5	7
W126	10.4	9.9	10.4	13.9	14.8
N60	134	100	123	190	214
N80	9	5	7	9	25
N100	1	0	1	1	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GRPO					
	1995	1996	1997	1998	1999
Month 1	0.01	0.33	-1.13	2.95	0.14
Month 2	-0.64	-0.74	-0.28	0.44	1.16
Month 3	-5.16	1.35	0.86	-2.07	-0.41

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GRPO					
	1995	1996	1997	1998	1999
April	0.01	0.33	-1.13	-2.07	0.14
May	-0.64	-0.74	-0.28	-1.01	1.16
June	-5.16	1.35	0.86	0.68	-0.41
July	2.98	2.98	-0.87	-1.38	7.86
August	1.51	-1.22	-2.44	-2.41	1.22
September	0.84	0.75	-2.18	-0.70	4.08
October	4.84	3.03	0.07	3.83	0.94

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and a few years in which concentrations reached 100 ppb for one hour. These levels of exposure are not likely to injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was low and similar over the five years. There does not appear to be any association between the Sum06 levels of ozone and drought over the five-year period. Soil moisture levels show that several years had one month of mild to severe drought, and the years with the highest and lowest exposures, 1999 and 1996 respectively, had favorable soil moisture conditions. The relatively uniform levels of ozone exposure also make it difficult to assess relationships between the W126 ozone exposure index and soil moisture. No associations are apparent between the

W126 indices of exposure and soil moisture. Soil moisture was normal in 1999, the highest ozone year, and there were four months of mild and moderate drought in 1998, the second highest exposure year. Of the three remaining years, two had the same level of exposure and had one and three months of drought, and the lowest exposure year, 1996, had one month of mild drought.

The low level of ozone exposure at Grand Portage National Monument makes the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 indices of exposure are satisfied, and exposure to levels greater than 100 ppb are rare. Months of drought stress are distributed over the five-year period, and are at times severe or numerous. These levels of drought limit the uptake of ozone and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, quaking aspen, and black cherry.

INDIANA DUNES NATIONAL LAKESHORE (INDU)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias exaltata</i>	Tall milkweed	Asclepiadaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Philadelphus coronarius</i>	Sweet mock-orange	Hydrangeaceae
<i>Pinus banksiana</i>	Jack pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

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Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for INDU					
	1995	1996	1997	1998	1999
Sum06	28	22	24	19	22
W126	25.8	-	-	38.1	39.2
N60	415	-	-	681	641
N80	111	-	-	138	182
N100	21	-	-	17	36

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

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Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at INDU					
	1995	1996	1997	1998	1999
Month 1	-1.34	1.98	2.01	-1.04	-2.28
Month 2	-0.91	5.70	1.31	2.26	-0.71
Month 3	-2.70	-1.48	2.15	1.10	-1.04

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at INDU					
	1995	1996	1997	1998	1999
April	1.82	0.48	-1.83	0.19	2.04
May	1.68	3.28	1.67	-1.04	-2.28
June	-0.23	1.98	2.01	2.26	-0.71
July	-1.34	5.70	1.31	1.10	-1.04
August	-0.91	-1.48	2.15	0.44	-0.74
September	-2.70	0.10	-0.26	-1.78	-2.26
October	-0.61	0.19	-0.17	-0.58	-2.20

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.
- There are no associations between the 90-day Sum06 accumulation period levels of ozone and soil moisture conditions. Soil moisture levels during year with the highest level of ozone, 1995, showed two months of mild and moderate drought, while the lowest ozone year, 1998, had one month of mild drought. The second highest ozone year, 1997, had favorable conditions, and the remaining two years had one and two months of mild and moderate drought. Assessment of relationships between the seasonal W126 level of exposure and soil moisture is

difficult since only three years of ozone data are available. However, there is no clear association between the level of ozone exposure and drought stress. Ozone exposures in 1999 and 1998 were high and similar in value, while the exposure in 1995 was considerably lower. There were four months of mild and moderate drought in 1999, and two of mild drought in 1998. The lowest ozone year, 1995, had two months of mild and moderate drought.

The risk of foliar ozone injury to plants at Indiana Dunes National Lakeshore is high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture reduces the likelihood of injury developing in any particular year. Although only three years of complete ozone data are available, the site is subject to potentially harmful levels of ozone annually, and there is no relationship between the level of ozone exposure and drought stress. The probability of foliar injury developing may be greatest during years such as 1998 when ozone levels exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and northern fox grape.

ISLE ROYALE NATIONAL PARK (ISRO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Aster macrophyllus</i>	Big-leaf aster	Asteraceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus banksiana</i>	Jack pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ISRO					
	1995	1996	1997	1998	1999
Sum06	7	4	6	6	9
W126	12.9	11.9	11.7	16.6	18.9
N60	184	136	146	243	282
N80	17	13	14	19	52
N100	3	1	3	3	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ISRO					
	1995	1996	1997	1998	1999
Month 1	0.87	4.11	-2.12	-1.59	-1.41
Month 2	1.25	-1.43	1.15	2.06	3.61
Month 3	-3.39	1.56	-2.13	-3.00	-1.08

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ISRO					
	1995	1996	1997	1998	1999
April	0.87	4.11	-2.12	-3.00	-1.41
May	1.25	-1.43	1.15	-3.03	3.61
June	-3.39	1.56	-2.13	0.04	-1.08
July	0.27	3.07	-0.59	-1.62	4.19
August	-0.79	-0.98	-0.40	-2.47	-0.18
September	-0.26	-1.03	-1.76	-2.36	-0.67
October	3.69	0.99	-1.33	-2.81	0.21

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was similar over the five years. There does not appear to be any association between the Sum06 levels of ozone and drought over the five-year period. Soil moisture levels show that each year had one or two months of mild to severe drought. The relatively uniform levels of ozone exposure also make it difficult to assess relationships between the W126 ozone exposure index and soil moisture, however no

associations between the indices of ozone exposure and soil moisture is apparent. The highest exposure year, 1999, had two months of mild drought. The second highest year, 1998, and the lowest year, 1997, had six and four months of mild to severe drought respectively. The remaining two years mid-level exposure years had one and two months of drought each.

The low level of ozone exposure at Isle Royale National Park makes the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 indices of exposure are satisfied, and exposures to levels greater than 100 ppb are rare. Months of drought stress are distributed over the five-year period, and are at times severe or numerous. These levels of drought limit the uptake of ozone and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, big-leaf aster, white ash, quaking aspen, and black cherry.

MISSISSIPPI NATIONAL RIVER AND RECREATION AREA (MISS)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias exaltata</i>	Tall milkweed	Asclepiadaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Aster macrophyllus</i>	Big-leaf aster	Asteraceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Philadelphus coronarius</i>	Sweet mock-orange	Hydrangeaceae
<i>Pinus banksiana</i>	Jack pine	Pinaceae
<i>Pinus rigida</i>	Pitch pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

<u>Ozone air quality data for MISS</u>					
	<u>1995</u>	<u>1996</u>	<u>1997</u>	<u>1998</u>	<u>1999</u>
Sum06	10	4	8	9	10
W126	13.5	10.2	11.2	15.3	14.6
N60	186	123	152	225	238
N80	33	8	14	13	13
N100	4	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MISS					
	1995	1996	1997	1998	1999
Month 1	-0.36	-0.17	-1.85	-1.52	3.14
Month 2	-2.38	-0.49	-0.69	-0.60	0.74
Month 3	2.68	0.58	5.48	1.75	2.58

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MISS					
	1995	1996	1997	1998	1999
April	0.71	-0.73	-1.98	-1.52	0.51
May	-0.36	-0.17	-1.85	-0.60	3.14
June	-2.38	-0.49	-0.69	1.75	0.74
July	2.68	0.58	5.48	-1.01	2.58
August	4.10	-3.09	0.55	0.07	1.21
September	-0.36	-1.45	-0.56	-2.59	0.24
October	4.08	1.65	0.24	0.22	-0.50

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are generally below the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was low and similar over the five years. There does not appear to be any association between the Sum06 levels of ozone and drought. In the highest ozone years, 1995 and 1999, there was one month of mild drought and normal soil moisture, respectively. Each of the mid-level exposure years, 1998 and 1997, had one month of mild drought, and the lowest exposure year, 1996, had normal soil moisture. The uniform levels of ozone also make it difficult to assess relationships between the W126 ozone exposure index and soil moisture, and no association is apparent between the two. There were three months of mild and moderate drought in 1998, the highest ozone year, no drought in the second highest year 1999, and two months of mild and severe drought in 1996, the lowest ozone year.

The low level of ozone exposure at Mississippi National River and Recreation Area makes the risk of foliar ozone injury to plants low. The Sum06 exposure threshold is satisfied, while the W126 threshold is not. Exposure to levels of ozone greater than 80 ppb is infrequent and exposure to 100 ppb is rare. Months of mild to severe drought are distributed over the five-year period. These levels of drought limit the uptake of ozone and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and northern fox grape.

MISSOURI NATIONAL RECREATION AREA (MNRR)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MNRR					
	1995	1996	1997	1998	1999
Sum06	2	0	4	3	5
W126	9.9	6.0	9.9	10.1	10.2
N60	139	60	141	141	133
N80	17	5	5	10	7
N100	2	0	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MNRR					
	1995	1996	1997	1998	1999
Month 1	-1.96	-0.28	1.22	-1.50	0.29
Month 2	-1.14	-1.13	-0.94	3.45	4.93
Month 3	2.70	3.33	-0.69	1.81	2.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MNRR					
	1995	1996	1997	1998	1999
April	3.32	-1.13	1.75	3.14	4.46
May	4.84	3.33	1.22	-1.50	0.29
June	-1.96	-0.75	-0.94	3.45	4.93
July	-1.14	1.47	-0.69	1.81	2.36
August	2.70	2.57	-0.85	3.32	0.15
September	2.45	2.17	0.87	-2.45	-1.87
October	2.92	-0.47	1.41	3.82	-1.78

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and two years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was low and similar over the five years. There does not appear to be any association between the Sum06 levels of ozone and drought over the five-year period. Soil moisture levels show that three years had one or two months of mild drought. The uniform levels of ozone exposure also make it difficult to assess relationships between the W126 ozone exposure index and soil moisture. No association is apparent between the W126 level of ozone exposure and soil moisture. Levels of drought were scattered and consisted mainly of one or two months of mild drought each

year; in one year, 1997, soil moisture was normal.

The low level of ozone exposure at Missouri National Recreation Area makes the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 indices of exposure are satisfied, and exposure to levels greater than 100 ppb are rare. Months of drought stress are mild and scattered over the five-year period. These levels of drought limit the uptake of ozone and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed and cut-leaf coneflower.

PICTURED ROCKS NATIONAL LAKESHORE (PIRO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PIRO					
	1995	1996	1997	1998	1999
Sum06	12	8	9	10	16
W126	23.1	18.9	19.0	25.3	28.9
N60	365	267	273	410	441
N80	74	48	57	61	124
N100	16	9	12	11	18

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PIRO					
	1995	1996	1997	1998	1999
Month 1	0.10	-0.21	-2.66	-2.79	-0.26
Month 2	-3.37	5.18	-1.08	0.00	-1.29
Month 3	0.77	-0.23	-0.46	-2.11	4.41

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PIRO					
	1995	1996	1997	1998	1999
April	2.43	4.17	-1.99	-1.86	-1.46
May	0.10	-2.38	2.02	-2.79	-0.26
June	-3.37	-0.21	-2.66	0.00	-1.29
July	0.77	5.18	-1.08	-2.11	4.41
August	-0.28	-0.23	-0.46	-1.30	-0.05
September	0.04	2.20	-1.98	-2.03	-0.70
October	4.37	2.86	-2.26	-2.09	1.50

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.
- Relationships between 90-day Sum06 accumulation period ozone levels and soil moisture are difficult to assess because ozone exposure was relatively similar over the five-year period. The pattern in which months of drought appeared during the five-year period appears unrelated to the Sum06 levels of ozone. The year with the highest ozone, 1999, had one month of mild stress while the next highest year, 1995, had one month of severe stress. The year with the lowest ozone, 1996, had normal soil moisture, but the next lowest year, 1997, had a month of mild and one of moderate stress. The relatively uniform levels of ozone also make it difficult to

assess relationships between the W126 exposure index and soil moisture. There are no apparent associations between the W126 levels of exposure and soil moisture. The two highest ozone years, 1999 and 1998, had two and six months of mild to moderate stress, respectively. The two years with the lowest ozone levels, 1996 and 1997, experienced one month of moderate stress and six months of mild and moderate stress, respectively.

The risk of foliar ozone injury to plants at Pictured Rocks National Lakeshore is moderate. The levels of ozone exposure consistently create the potential for injury, however consecutive months of low soil moisture may reduce the likelihood of injury developing in a particular year. Since there are no apparent relationships between the levels of ozone exposure and soil moisture conditions, and since entire growing seasons appear to be characterized by either largely favorable or unfavorable soil moisture conditions, the levels of risk vary considerably among years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995, 1996 and 1999 when soil moisture levels are under limited drought that does not place long-term constraints on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, big-leaf aster, white ash, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.

SAINT CROIX/LOWER ST. CROIX NATIONAL SCENIC RIVER (SACN)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias exaltata</i>	Tall milkweed	Asclepiadaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Aster macrophyllus</i>	Big-leaf aster	Asteraceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Philadelphus coronarius</i>	Sweet mock-orange	Hydrangeaceae
<i>Pinus banksiana</i>	Jack pine	Pinaceae
<i>Pinus rigida</i>	Pitch pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

<u>Ozone air quality data for SACN</u>					
	<u>1995</u>	<u>1996</u>	<u>1997</u>	<u>1998</u>	<u>1999</u>
Sum06	11	4	7	8	11
W126	13.4	8.8	9.7	15.7	16.8
N60	193	98	124	229	271
N80	28	5	6	16	20
N100	3	0	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SACN					
	1995	1996	1997	1998	1999
Month 1	-0.12	-0.42	-1.52	-2.14	1.63
Month 2	-2.60	-0.24	2.51	-1.41	0.74
Month 3	0.76	0.91	-0.11	0.74	5.23

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SACN					
	1995	1996	1997	1998	1999
April	1.20	-0.42	-2.57	-2.14	0.15
May	-0.12	-0.24	-1.20	-1.41	1.63
June	-2.60	0.91	-1.52	0.74	0.74
July	0.76	2.55	2.51	-2.39	5.23
August	3.95	-2.56	-0.11	-1.36	1.39
September	-0.86	-0.23	-0.74	-2.74	0.00
October	4.52	3.21	-0.10	-0.38	-0.71

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb and in most years there were no hours at this level. These levels of exposure are not likely to injure vegetation.

- Relationships between 90-day Sum06 accumulation period ozone levels and soil moisture are difficult to assess because ozone exposure was low and relatively similar over the five-year period. The pattern in which drought occurred during the five-year period appears unrelated to the Sum06 levels of ozone. The two years with the highest exposure, 1995 and 1999, had one month of moderate stress and normal soil moisture, respectively. The years with mid-level exposures, 1998 and 1997, had two months of mild and moderate drought and one month of mild drought, while the year with the lowest ozone, 1996, had favorable soil moisture. The relatively uniform levels of ozone also make it difficult to assess relationships between the W126 exposure index and soil moisture. Overall, there are no apparent associations between the W126 levels of exposure and soil moisture. The two highest ozone years, 1999 and 1998, had favorable moisture conditions and five months of mild and moderate stress, respectively. The year with the lowest ozone, 1996, experienced one month of moderate stress, while the two years with intermediate levels of ozone had one and three months of moderate and mild stress.

The low level of ozone exposure at Saint Croix/Lower St. Croix National Scenic River makes the risk of foliar ozone injury to plants low. The Sum06 threshold is intermittently satisfied while the W126 threshold is not. Exposure to ozone greater than 80 ppb is uncommon and exposure to 100 ppb is rare. Months of drought are distributed over the five-year period, reach moderate levels of stress and occur for several consecutive months. These levels of drought limit the uptake of ozone and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and northern fox grape.

SLEEPING BEAR DUNES NATIONAL LAKESHORE (SLBE)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias exaltata</i>	Tall milkweed	Asclepiadaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Aster macrophyllus</i>	Big-leaf aster	Asteraceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Philadelphus coronarius</i>	Sweet mock-orange	Hydrangeaceae
<i>Pinus banksiana</i>	Jack pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

<u>Ozone air quality data for SLBE</u>					
	<u>1995</u>	<u>1996</u>	<u>1997</u>	<u>1998</u>	<u>1999</u>
Sum06	9	6	6	6	15
W126	30.4	20.4	21.4	27.0	27.1
N60	487	312	322	441	419
N80	116	55	58	71	114
N100	20	12	8	9	12

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SLBE					
	1995	1996	1997	1998	1999
Month 1	-0.30	1.85	-2.79	-2.52	-0.36
Month 2	-1.65	2.50	-0.46	-0.72	1.04
Month 3	-0.17	-1.04	0.95	-1.30	5.34

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SLBE					
	1995	1996	1997	1998	1999
April	1.89	3.10	-2.29	-1.07	-1.75
May	-0.30	-0.67	3.14	-2.25	-0.36
June	-1.65	1.85	-2.79	0.05	1.04
July	-0.17	2.50	-0.46	-2.52	5.34
August	2.10	-1.04	0.95	-0.72	-0.64
September	-1.23	0.78	-2.76	-1.30	-0.47
October	1.87	1.86	-1.51	-1.08	-0.41

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 threshold was satisfied in two years and the W126 criteria satisfied in all five of the years.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in several years. These levels of exposure can potentially injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. The years with the two highest Sum06 indices, 1995 and 1999, experienced one month of mild

drought and normal soil moisture, respectively. In 1997, a mid-level exposure year, there was one month of mild drought, and in the two years with the same and lowest exposure, 1996 and 1998, had one month of mild drought and two months of mild and moderate drought, respectively. There is also no association between the W126 levels of exposure and the soil moisture. The W126 ozone exposure indices break down into two levels of similar exposures. The three highest ozone years, 1995, 1998, and 1999, experienced one to five months of mild and moderate stress, while the two lower ozone years, 1996 and 1997, experienced one to four months of mild to moderate stress.

The risk of foliar ozone injury at Sleeping Bear Dunes National Lakeshore is high. The threshold levels for injury are consistently satisfied for both the Sum06 and the W126 indices of exposure. The N-values indicate in some years there are frequent exposures to concentrations of ozone greater than 80 ppb, with numerous hours of exposure to 100 ppb. Mild to moderate drought conditions occur independent of the level of ozone exposure and reduce the uptake by plants. It is anticipated that the risk of injury may be greatest in years such as 1995, 1996 and 1999 when levels of exposure exceed injury thresholds and soil moisture conditions generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.

VOYAGEURS NATIONAL PARK (VOYA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus banksiana</i>	Jack pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for VOYA					
	1995	1996	1997	1998	1999
Sum06	6	3	8	6	8
W126	9.7	8.7	13.2	12.2	12.3
N60	116	96	170	137	175
N80	6	0	8	0	5
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at VOYA					
	1995	1996	1997	1998	1999
Month 1	0.01	-1.35	-1.13	0.44	0.14
Month 2	-0.64	0.33	-0.28	-2.07	1.16
Month 3	-5.16	-0.74	0.86	-1.01	-0.41

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at VOYA					
	1995	1996	1997	1998	1999
April	0.01	0.33	-1.13	-2.07	0.14
May	-0.64	-0.74	-0.28	-1.01	1.16
June	-5.16	1.35	0.86	0.68	-0.41
July	2.98	2.98	-0.87	-1.38	7.86
August	1.51	-1.22	-2.44	-2.41	1.22
September	0.84	0.75	-2.18	-0.70	4.08
October	4.84	3.03	0.07	3.83	0.94

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. There does not appear to be any association between the Sum06 levels of exposure and drought. Three years had one month of mild or moderate drought, one year had two months of drought, and one had favorable conditions. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake

of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone, 1997, had three months of mild and moderate drought. The two next highest years, 1998 and 1999, had the same level of ozone, but experienced four months of mild and moderate drought and favorable moisture conditions, respectively. The lowest ozone year had one month of mild drought, and the second lowest year had one month of severe drought.

The low levels of ozone exposure at Voyageurs National Park make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied, and there are only a few hours above 80 ppb and no hours above 100 ppb. Months of drought in most high ozone years constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.